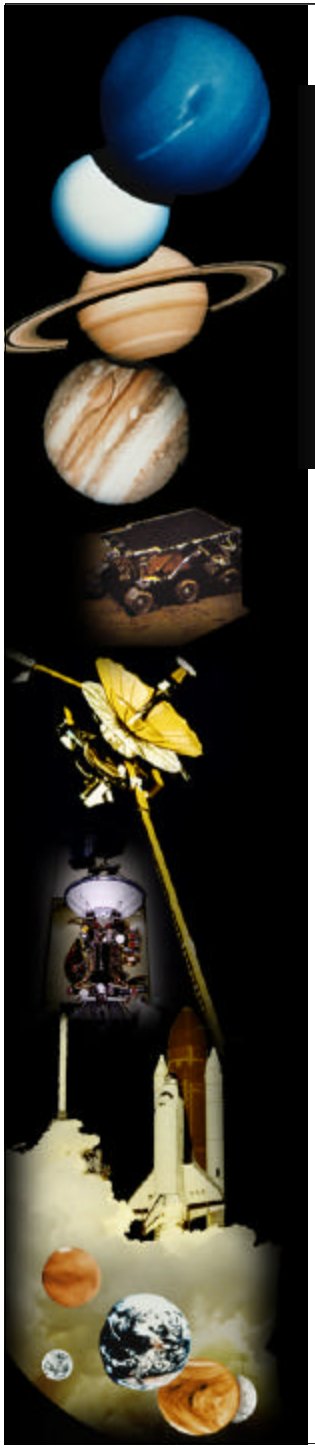


Overview of DOE's Plans for Radioisotope Power Systems for Future NASA Space Exploration Missions

Earl Wahlquist, Associate Director
Office of Space and Defense Power Systems
U.S. Department of Energy
Washington, D.C.

July 23, 2002

The Department of Energy

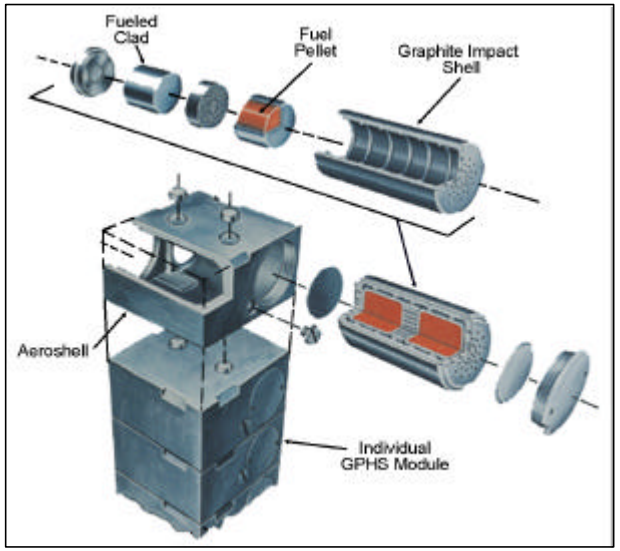
- **Designs, develops, assembles, tests and delivers Radioisotope Power Systems for NASA space exploration missions**
- **Assembles, tests and delivers Radioisotope Heater Units**
- **Provides:**
  - Safety analyses for input to mission EISs
  - Final Safety Analysis Report and mission launch approval support
  - Ground support at the launch site
  - Emergency Response Planning

Topics

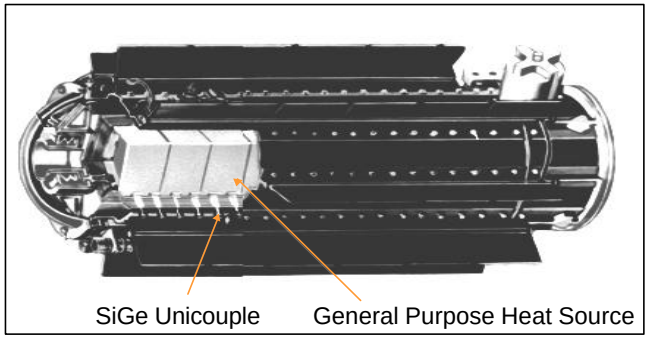
- **Background**
- **Existing Assets**
- **Radioisotope Power Systems for Future Missions**
- **Other Mission Support**

Radioisotope Power Systems Key Components

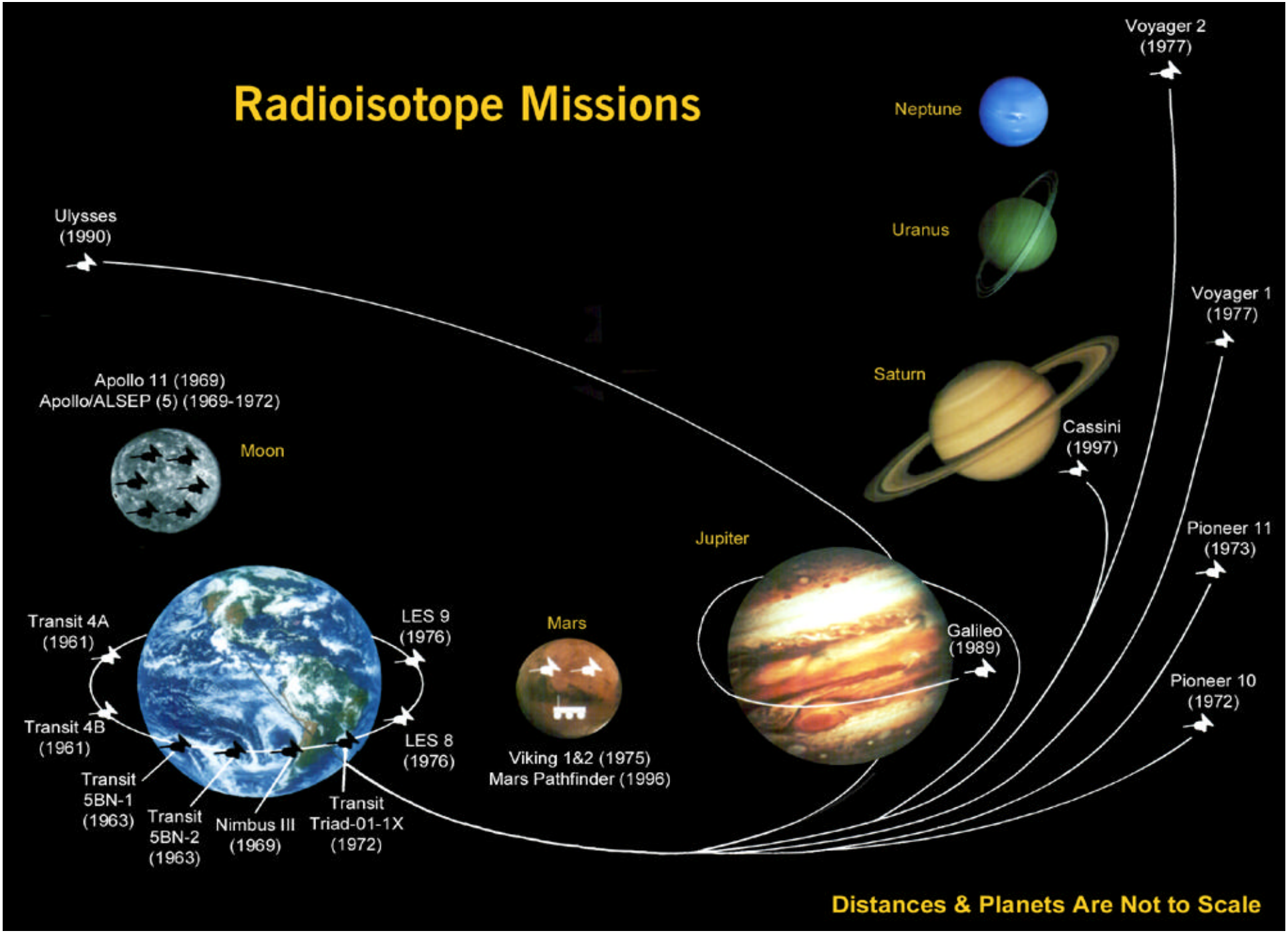
- **Pu-238 fuel (generates decay heat)**
  - Alpha-emitter, 87-year half life
  - Nonweapons material
  - Highly insoluble
- **Ir Cladding (encases the fuel)**
  - Fuel containment (normal operations or accidents)
  - High melting point -- thermal protection
  - Ductile -- impact protection
- **Graphite heat source (protects fuel & cladding)**
  - Impact shell -- impact protection
  - Insulator -- protect clad during re-entry
  - Aeroshell -- prevent burnup during re-entry
- **Converter (converts heat to electricity)**
  - Thermoelectrics -- reliable, but low efficiency (7%)
  - Stirling -- high efficiency (20-25%), under development
- **Radiator (rejects excess heat)**



General Purpose Heat Source Module



Radioisotope Thermoelectric Generator


Radioisotope Missions
Voyager 2 (1977)
Neptune
Ulysses (1990)
Uranus
Voyager 1 (1977)
Apollo 11 (1969)
Apollo/ALSEP (5) (1969-1972)
Moon
Saturn
Cassini (1997)
Jupiter
Pioneer 11 (1973)
Transit 4A (1961)
LES 9 (1976)
Mars
Galileo (1989)
Transit 4B (1961)
LES 8 (1976)
Pioneer 10 (1972)
Viking 1&2 (1975)
Mars Pathfinder (1996)
Transit 5BN-1 (1963)
Transit 5BN-2 (1963)
Nimbus III (1969)
Transit Triad-01-1X (1972)
Distances & Planets Are Not to Scale

Light-Weight Radioisotope Heater Unit (LWRHU)

1 Watt, 1.8 gm Pu-238

Recent LWRHU Flights

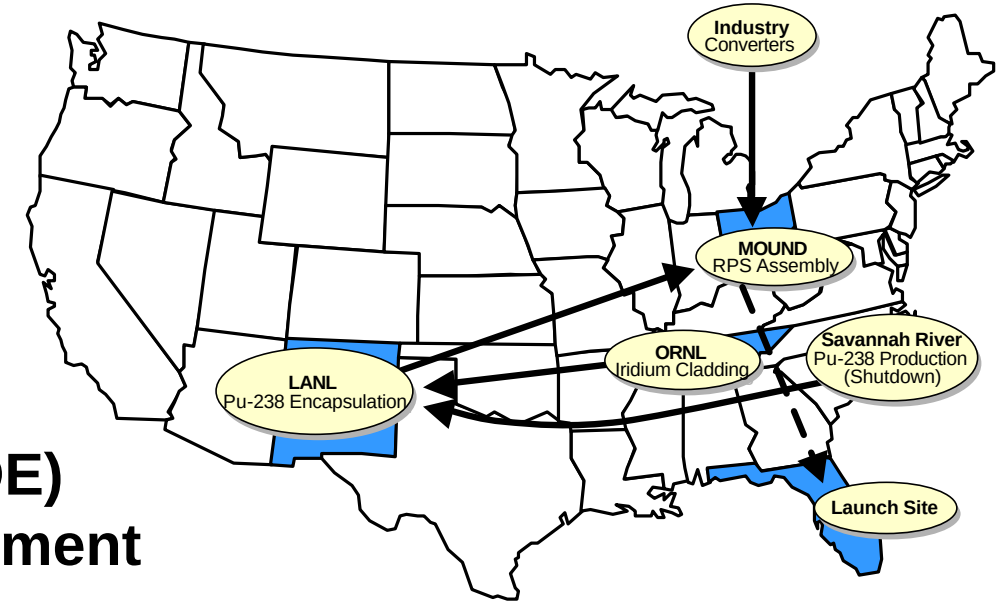
Cassini (117 LWRHUs)

Mars Pathfinder-Sojourner (3)

Galileo (120)

Radioisotope Power System Fabrication

- **DOE maintains infrastructure**
  - Nuclear facilities (LANL, ORNL, Mound)
  - Safety analyses
  - Pu-238 supply
    - Re-establish domestic capability
    - Interim Russian purchase (using NASA funds)



- **NASA funds (through DOE) mission-specific development**
  - System design/development
  - Flight hardware
  - Production/acquisition cost of Pu-238 used in actual missions

Existing Assets

Generators

- E-8 being assembled and fueled for potential Pluto mission
- F-5 Galileo/Ulysses/Cassini spare RTG (to be defueled)

LWRHUs

- 87 LWRHUs in inventory
- 22 planned for Mars 03 Mission

Pu-238

- 9 kgs in inventory
- 1 kg being purchased from Russia
- Additional purchases planned for FY 2003 and beyond

Radioisotope Power Systems For Future NASA Missions

Selection of Radioisotope Power System

- **Standard 300 W_e RTG used on 1990s mission (*e.g.*, Cassini)**
- **New Generator Required for Future Missions**
  - Cassini RTG will not operate effectively or reliably on planets with atmospheres
  - Modular generator (~100W_e) to support variety of missions
  - Higher efficiency could reduce Pu-238 requirement
- **Dual approach to system development being pursued**

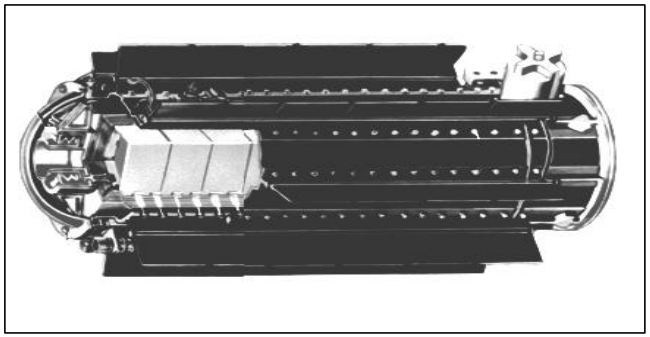
New Radioisotope Power Systems Requirements

- **Shall provide at least 110 watts**
- **Shall operate in deep space and on the surface of Mars**
- **Shall provide power for missions up to 14 years**
- **Shall be as small and light as possible, maximizing specific power**
- **Shall operate over a voltage range of 23-36 Vdc and provide near-maximum power at 28 Vdc**
- **Shall be designed to minimize safety impact of components on the integrity of the GPHS modules**

Radioisotope Power System Development
(100 Watt Generator Modules for Future Missions)

Multi-Mission RTG

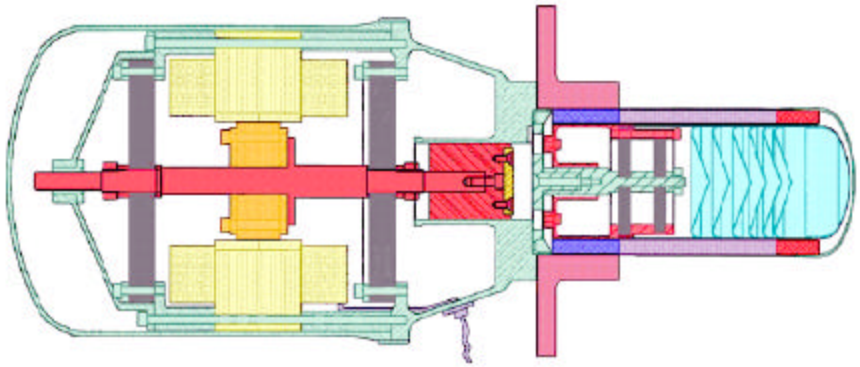
- **Based on thermoelectrics used in past NASA missions**
  - Silicon Germanium for Voyager, Galileo, Ulysses and Cassini
    or
  - Lead Telluride/TAGS for Pioneer, Viking, NIMBUS and ALSEP
- **Use 8 heat source modules (4 kgs of Pu-238)**
- **Procurement initiated**
  - Request for Proposals - June 2002
  - Contractor selection - Fall 2002



Radioisotope Thermoelectric Generator

Radioisotope Stirling Generator (RSG)

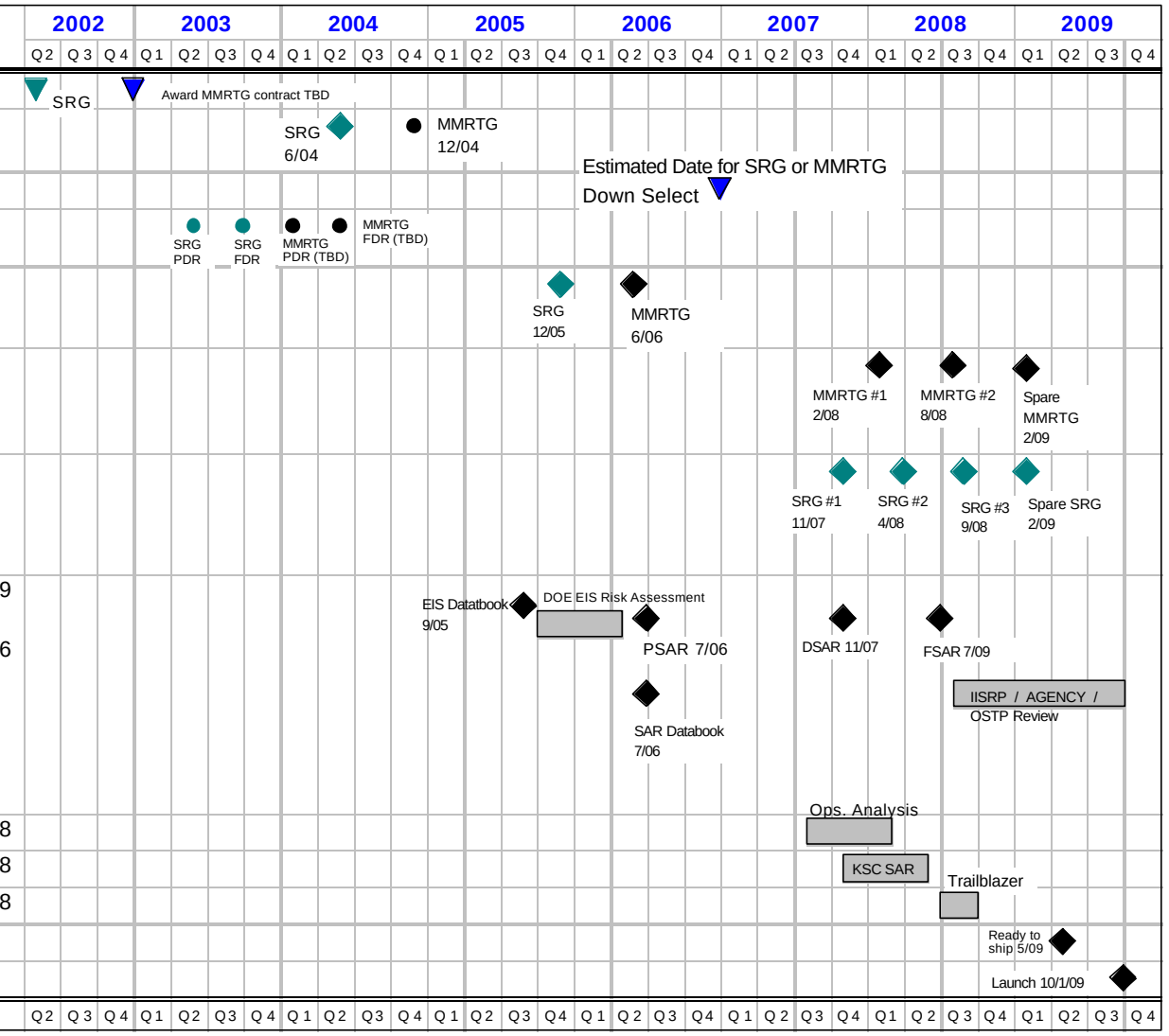
- **Based on demonstrated technology**
  - Terrestrial engine life tests
  - Key component life tests
  - Cryocoolers flown in space
- **Use 2 heat source modules (1 kg of Pu-238)**
- **Procurement completed**
  - Phase 1 conceptual designs complete
  - Contractor selected - Lockheed Martin Astronautics
  - Phase IIA Engineering Unit underway - May 2002



Stirling Engine

Draft DOE Schedule

Activity Name	Start Date	Finish Date
System Contractor Award	1/1/03	
Engineering Unit	12/1/04 6/1/04	
	1/1/07	
Design Reviews	6/1/03 10/1/03	
Qualification Unit	6/1/06 12/1/05	
Flight Units (MMRTG)	2/1/08 8/1/08 2/1/09	
Flight Units (SRG)	11/1/07 4/1/08 9/1/08 2/1/09	
EIS/Launch Approval	8/1/08	9/30/09
	9/1/05	
DOE EIS Risk Assessment	10/1/05	4/30/06
PSAR	7/1/06	
SAR Data Book	7/1/06	
Draft FSAR	11/1/07	
FSAR	7/1/08	
KSC Operations Analysis	8/1/07	2/29/08
KSC SAR (10CFR 830)	11/1/07	5/31/08
Trailblazer	7/1/08	9/30/08
Ready to Ship	5/1/09	
Launch (10/09)	10/1/09	



Status of Pu-238 Supply

- **Finite inventory of Pu-238**
  - Savannah River production capabilities being shut down
  - Domestic inventory set aside for National Security applications
  - 9 kgs purchased from Russia for space missions
  - Could have potential need of as much as 29 kgs through this decade
- **Plans for the future**
  - Re-establish domestic production capability (considered as part of Nuclear Infrastructure PEIS)
  - Additional purchases from Russia (current contract expires in Dec. 2002)

Plans for Pu-238 Supply

- **Record of Decision issued in January 2001 to re-establish domestic production capability**
  - Irradiation in the Advanced Test Reactor and High Flux Isotope Reactor
  - Processing at Oak Ridge National Laboratory
  - 5-6 years to re-establish capability
- **Interim purchase from Russia pending completion of DOE capability**

Other Items of Interest

Safety Analysis

- NASA provides launch vehicle data book to DOE
- DOE performs nuclear risk assessment
  - Support NASA NEPA process
  - Produce formal safety documentation for launch approval

Ground Operations at Launch Site

- DOE transports RPS to NASA launch site
- DOE establishes requirements for handling RPS during storage and spacecraft integration
- DOE supports emergency response planning

Summary of RPS

- **DOE maintains an active program and infrastructure to support NASA**
- **DOE will develop (using NASA funds) advanced radioisotope power systems (thermoelectric and Stirling) to meet NASA's future needs**
- **DOE has issued a Record of Decision to re-establish a domestic supply of Pu-238 with interim Russian purchase**
- **DOE looks forward to continuing to provide RPS in support of NASA**

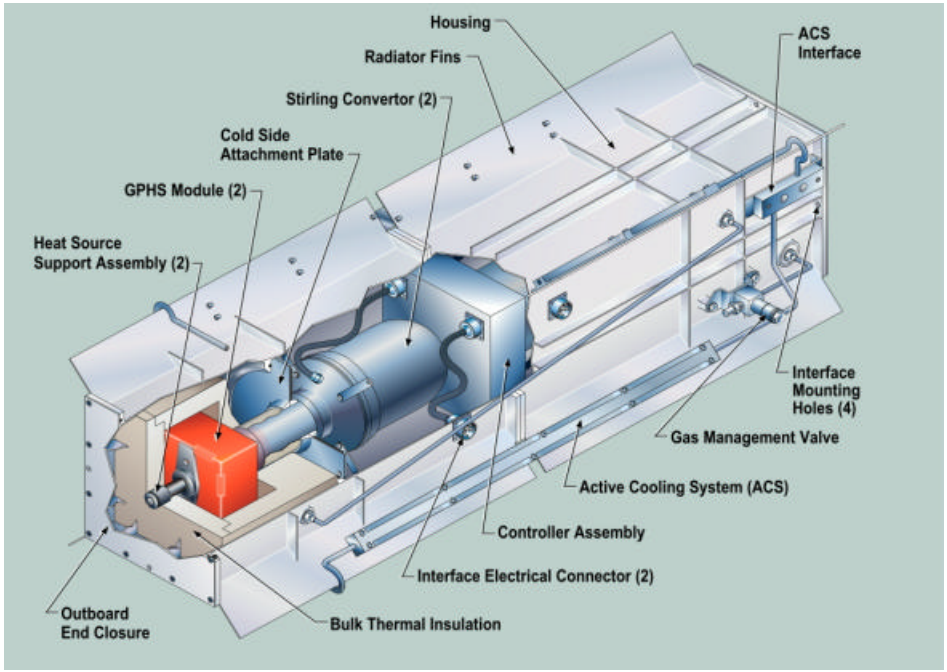
Backup

DOE MMRTG Design Assumptions

- Dimensions (nominal estimate)
  - 43 – 84 cm (17 – 33 inches) overall diameter (fin tip to fin tip)
  - 53 – 58 cm (21 – 23 inches) long
- Mass (estimate with 8 enhanced GPHS modules)
  - 24 – 34 kg
- Thermoelectric Temperatures (Hot and Cold Side)
  - PbTe 550° C – 165° C
  - SiGe 1000°C - 300°C
- Heat Input
  - Approx. 2000 Watts thermal (Wt) using 8 GPHS modules
- Waste Heat

  1860 Wt (using a thermoelectric conversion efficiency of 7.0%)

SRG Design Concept



- ***Two GPHS Modules***
- ***Two Stirling TDC-55 Convertors***
- ***BOM Power: 114 We***
- ***EOM Power: 93.4 We***
- ***Mars Rover Mission Life: 3yr***
- ***Deep Space Mission Life: 100,000 hr***
- ***Voltage 28 +/- 0.2 VDC***
- ***Mass: 27 kg***
- ***Dimensions: 35” long x 10.5” wide (across fins)***